NASA TT F-140

NASA TT F-140

50760

TECHNICAL TRANSLATION

F-140

EXPLOSION WELDING

By V. S. Sedykh, A. A. Deribas, Ye. I. Bichenkov,
and Yu. A. Trishin

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON March 1963

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL TRANSLATION F-140

EXPLOSION WELDING

By V. S. Sedykh, A. A. Deribas, Ye. I. Bichenkov,
and Yu. A. Trishin

Translation of "Svarka vzryvom"
Svarochnoye Proizvodstvo, No. 5, 3-6, 1962

Available from

Office of Technical Services
Department of Commerce
Washington 25, D.C.

Price $0.50

EXPLOSION WELDING

V. S. Sedykh, A. A. Deribas,
Ye. I. Bichenkov, Yu. A. Trishin

Institute of Hydrodynamics,
Siberian Branch of the AS USSR

Owing to the development of high pressures, the behavior of a /3
metal in the solid phase subjected to impact loading under cumulative conditions is determined not by its strength and plasticity, but solely by the inertial forces, as with an ideal liquid [1]. A cumulative effect, i.e., a marked increase in the local action of an explosion, is developed by a cylindrical charge of high explosive (HE), provided at one end with a hemispherical or conical cavity coated with a metal lining a few millimeters thick, and detonated from the other end. When such a charge is exploded, the elements of the metal lining of the cumulative-effect cavity acquire velocities of the order of 1,000 to 2,500 m/sec, directed normal to the initial position of the surface, and the lining begins to be compressed. The redistribution of

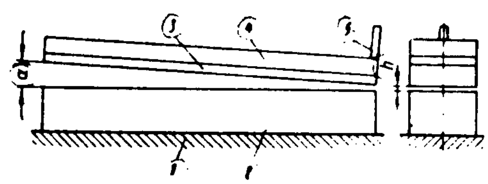
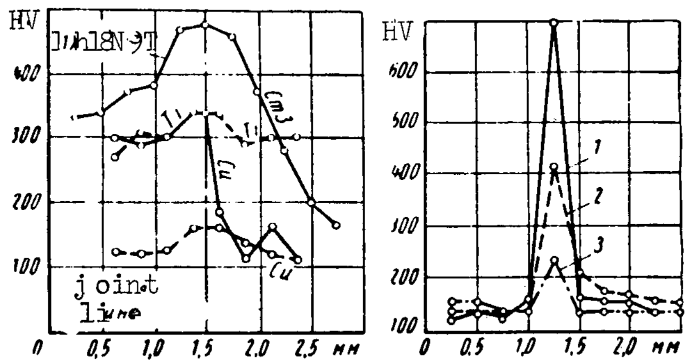


Fig. 1. Arrangement of parts for explosion welding: 1 -- rigid base; 2 and 3 -- plates to be welded; 4 -- explosive charge; 5 -- detonator; α -- angle between plates; h -- least distance between plates.



a b

Fig. 2. Curves of microhardness, measured across heterogeneous joints between 1Kh18N9T + St. 3, Ti + Ti, Ti + Cu, Cu + Cu (a) and plates of St. 3 steel (b): 1 -- after welding; 2 -- after tempering from 300°; 3 -- after tempering from 400°.

velocities during the compression process causes a sharp increase in the energy density in the inner layers of the lining and an increase of several million atmospheres in the pressure, as the elements converge on the axis. As a result, a metal "wire" or cumulative jet is forced out from the center part of the compressed lining in an axial direction and at a velocity of up to 10^4 m/sec, while the rest of the metal lining is converted into a monolithic mass which, together with the jet resembles a "pestle" in shape [2].

It has been experimentally established that the conversion of the lining into a "pestle" and the formation of the cumulative jet occur while the metal is in the solid phase. The jet consumes from 6 to 11% of the mass of the lining, due exclusively to the flow of metal from its inner surface. The metal of the "pestle" has an oriented microstructure, drawn out along the longitudinal axis of the cavity. The degree of orientation and elongation of the grains increases in a direction from the periphery to the axis of the "pestle" [2].

In the theory of cumulative processes, one problem relates to the motion of a plate, propelled by a flow of HE detonation

a)

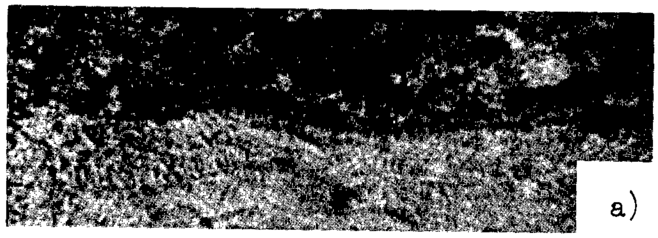
b)

Fig. 3. Microstructure of welded St. 3 + St. 3 joint: a -- across plates; b -- along plates. X 450.

products with a plane front against a plane obstacle disposed at a sharp angle [2]. When these collide, a pressure of the order of 10^6 abs. atm. develops at the apex of the angle between the plate and the obstacle, evidently again forming something like a cumulative jet, which entrains the surface layers of metal from the plates.

On impact the tangential component of the velocity of the plate should cause its surface layers to flow along the surface of the obstacle. Even in an ideal liquid, the resulting tangential discontinuity in velocity thus formed is absolutely unstable, and this conditions the development of the arbitrary, even insignificant perturbations that follow its occurrence [3].

We may assume that upon the collision of plates oriented at a certain angle to each other the cumulative jet will clean their



a)

b)

Fig. 4. Microstructures of joints:
a -- 1Kh18N9T steel (top) and St. 3 steel across the plates. X 600.
b -- hardened zone in 1Kh18N9T. X 1,350.

surfaces, and that the perturbations developing at the points where they collide will enable them to approach close enough for a welded joint to form.

In order to test this reasoning, we carried out the following experiments.

One of the plates to be welded 2 was mounted on massive base 1 (Fig. 1). The other plate 3, carrying charge 4, was placed at distance h above the surface of the first, and inclined at an angle α to its longitudinal axis. The charge was exploded by means of detonator 5 at the end corresponding to the apex of the angle α. The explosive employed was granular hexogen (trimethylene trinitramine $C_3H_6O_6N_6$), density 1.2 g/cm^3, with a detonating velocity $D = 6{,}600$ m/sec and a pressure of the detonation products $P = 130 \cdot 10^3$ abs. atm. [4].

Attempts to use more powerful condensed explosives of the trotyl type (trinitrotoluene $C_6H_2(NO_2)_3CH_3$, density 1.52-1.6 g/cm^3, D = 6,600-7,000 m/sec, P = $(170\text{-}200)\cdot 10^3$ abs. atm.) or TG-50/50 (50% fusion of trotyl and hexogen, density 1.6 g/cm^3, D = 7,000 m/sec, P = $300\cdot 10^3$ abs. atm.) did not give positive results and showed that the choice of explosive greatly influences the behavior of the metal following an explosion. Even in small charges, the power of the condensed explosive was almost always enough to cause considerate destruction to the specimens.

1Kh18N9T and St. 3 steels, M3 copper, OT4 titanium alloy, and ADN aluminum were used to make plates for welding, measuring 150-200 mm in length, 20-40 mm in width, and 1.5-15 mm (plate 2) and 1.5-4 mm (plate 3) in thickness. The following materials were welded: St. 3 + St. 3, and St. 3 + 1Kh18N9T, M3 + M3, OT4 + OT4, OT4 + M3, 1Kh18N9T + M3, and 1Kh18N9T + ADN. In these experiments the variables for plates of the same size were the distance h between the surfaces of the plates, the angle α along their longitudinal axis, and the thickness of the charge. to p 7

As a result of these experiments it was established that when $\alpha = 0°$, increasing h from 0 to 20 mm and the thickness of the charge from 5 to 35 mm does not lead to the formation of a joint between the various pairs of materials. The collision between the plates merely polishes their surfaces to mirror brightness, obliterating traces of machining and trimming, or, if the charge is too large, destroys them.

Analogous results were obtained for the action of a shock wave through incompressible dense media on plates with contacting surfaces, as described in [7].

For a minimum angle $\alpha = 0°35'$, h = 2 mm, and a charge thickness of 5 mm, plates made of St. 3 steel give weak adhesion and a slight waviness of the surfaces. As α increases, so does the adhesion of the plates and the degree of waviness, and at $\alpha = 2°18'\text{-}4°35'$ it was possible to destroy the joint only along the "base" metal. Joints were obtained between all the other pairs of materials at $\alpha = 2\text{-}7°$, charge thicknesses of 5-20 mm, and h = 2 mm. The strength of the welded joints increased to a certain limit with increase in the angle α and the thickness of the charge. According to preliminary data, the ultimate shear strength of joints between steels 1Kh18N9T and St. 3 is 54-57 kg/mm^2, between 1Kh18N9T steel and M3 copper 16.8 kg/mm^2, and between the latter steel and ADN aluminum 7.2 kg/mm^2. In these tests destruction of the specimens generally affected the weaker metal of the pair and occurred at a certain distance from the plane of the joint, this being attributable to hardening of a zone 10-100 microns wide around the weld, as revealed by measurements of the microhardness

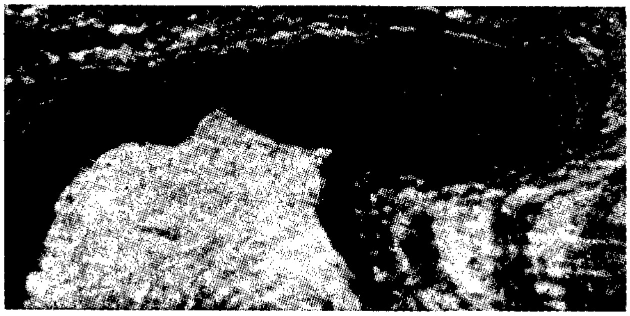


Fig. 5. Microstructure of joint between M3 copper (top) and 1Kh18N9T steel; dark regions in copper -- most heavily deformed grains, section cut along joint. X 600.

Fig. 6. Microstructure of joint between copper plates; section cut at an angle of 45° to the longitudinal axis of the plates. X 450.

of the welded joints (Fig. 2). The hardest such zone (HV 700) was obtained for a joint with plates of 1.5 mm thick St. 3 steel. After heat treatment (tempering from 300 and 400°C) the hardness was reduced to HV 420 and HV 260, respectively (Fig. 3).

Metallographic investigation of the joints showed that, except in this case, the hardened zones were formed as a result of heavy deformation of the thin surface layers of the plates. The hardened zone between plates of St. 3 steel has regions with a martensitic, acicular structure, different from that of the original material (Fig. 4, a,b). After heat treatment (quenching in water from 900°C), the hardness of thin specimens of St. 3 steel in the post-rolling state rose to HV 380 (light grains of ferrite) and to HV 470 (dark, acicular structure). It may be assumed that the structural transformations in certain sections of the weld-affected zone in plates made of St. 3 steel are due to the impact or to a combination of impact and the heating of the surface layers of metal to considerable temperatures as a result of their instantaneous deformation. There may be some interest in investigating this possibility as a method of increasing the strength of metals.

Metallographic investigation of the structure of the joints gave the following results.

1. The welded surfaces of the joints were free of oxide films and other nonmetallic inclusions that normally complicate the welding of metals in the solid phase. Obviously, these are removed from the plate surfaces by the cumulative jet.

2. The joint boundary along the plates is a clearly expressed wavy line, and that across the plates almost a straight one. Presumably, the plane surfaces of the plates are transformed into wavy ones by the action of perturbations developed by the tangential discontinuity in velocity at the points of contact between the plates on collision. It is known that, given sufficiently pure surfaces, metals can be made to adhere by applying tangential displacements alone [5]. The simultaneous formation of "waves" in the surfaces joined at the moment of collision, together with the tangential displacement, creates ideal conditions for the approach of the plates to within the distances necessary for the formation between them of a metallic bond, at the same time considerably increasing the area of the joint.

The latter circumstance may also serve to explain the destruction of specimens outside the plane of the joint during testing.

3. Joints between different metals (Cu + Ti, Fe + Al, Fe + Cu) are free of intermediate chemical components. The reason for this is the briefness of the welding process of the order of microseconds, which, even with the considerable increase in the temperature of the surface layers of metal, due to the impact and the deformation of the plates, is clearly insufficient for diffusion

6 p 8

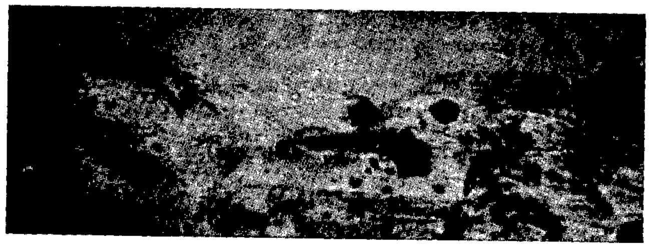


Fig. 7. Microstructure of joint between 1Kh18N9T steel (top) and ADN aluminum; section cut at an angle of 45° to longitudinal axis of plates. X 500.

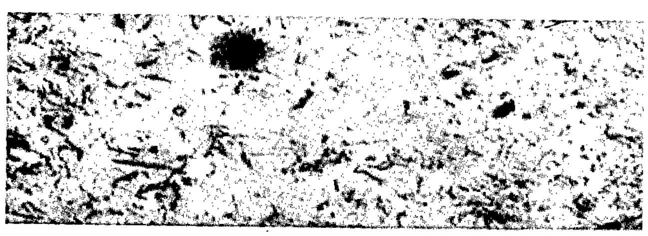


Fig. 8. Microstructure of joint between OT4 alloy plates; section cut across plates. X 450.

processes to occur.

The microstructures of the welded joints are shown in Figs. 5-8.

[The investigation described also made it possible to establish, to a first approximation, the dynamics of the explosion welding process.] and [illegible]

After the explosion is triggered by detonator 5 (Fig. 1), a plane detonation wave propagates along the layer of explosive 4 at

a velocity D ≈ 6,600 m/sec. The pressure behind its front is relieved by explosion waves, propagated sideways and upwards from the free surfaces of the charge and imparting to the plate 3 a momentum directed downwards along the normal to the initial position of its surface. As a result of the finiteness of the velocity D, the elements of plate 3 successively acquire a velocity v and approach the surface of plate 2 at an angle $\gamma = \alpha + \beta$, where α is the initial angle between /5
the surfaces of plates 2 and 3, and $\beta = \arctan \frac{v}{D}$.

Calculations show that a plate 3, 20 mm wide, 2 mm thick, and with a density of 7.8 g/cm^3, displaced by a charge of hexogen 10 mm thick and with a density of 1.2 g/cm^3, acquires a velocity v = 2,000 m/sec, which can be resolved into a normal and a tangential component with respect to the surface of plate 2: $v_n = v \cos \alpha$; $v_t = v \sin \alpha$.

The action of the normal component v_n leads to the development of high pressures at the point of impact between the plates. The table below shows values of these pressures as a function of v_n, calculated by means of the equation of state of a metal given in reference [6].

TABLE

v_n in m/sec	800	1700	2000	4000	5200	8800
$p \cdot 10^6$ in abs. atm.	0.14	0.34	0.64	1.06	1.66	3.65

The length of time the pressure acts at the point of impact is determined by the time taken by the relief wave to arrive from the nearest free surface $t = \frac{2\delta}{C}$, where δ is the thickness of plate 3 (Fig. 1) and C is the speed of sound in the metal of the plate.

For a steel plate 2 mm thick, $t = 10^{-6}$ sec. For impact directed normal to the surface of plate 2, the component v_t, causing shear deformation, is equal to zero during time t, since the rotation

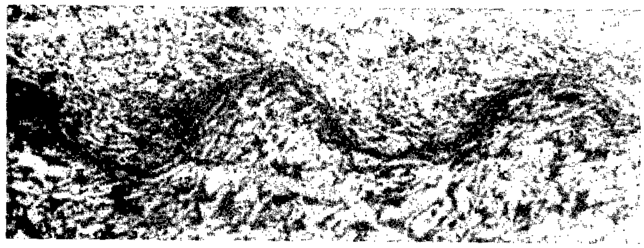


Fig. 9. Microstructure of joint between St. 3 steel plates mounted parallel; section cut along the plates from part of the joint 450 mm from their beginning. X 120.

of plate 3 through the angle β does not affect its value. Thus, the relief wave may tear the upper plate away from the lower plate 2. These factors were responsible for our failure to join plates aligned parallel to each other, since the approach of plate 3 to plate 2 at an angle β only formed a surface-cleaning cumulative jet, i.e., created the first of the conditions necessary for the formation of a joint.

However, by varying the configuration of the surface of the propelled plate, it is possible to make its surface layers at the point of impact with the fixed plate move with a certain tangential velocity even when the two plates are parallel. In particular, we succeeded in welding plates 550 mm long (St. 3 steel + St. 3 steel, and M3 copper + L62 brass), the upper (propelled) plates being bent at an angle $\alpha = 2°$ with respect to the lower only over an initial section 150 mm long. In this case the joint line was again wavy over its entire length with characteristic whorls (Fig. 9). Apparently, this is a possible means of obtaining welded joints of practically unlimited length and area. However, the mechanism by which such joints are formed requires further study and clarification.

CONCLUSIONS

1. The possibility of welding metals of the same and different types, and also of obtaining welded joints of large area, by means of an explosion has been experimentally established.

2. Explosion welding makes it possible to obtain welded joints between metals and alloys of different kinds in the solid phase and without the formation of intermediate chemical components. In explosion welding the welded joint is formed by the action of the energy of the volatile detonation products of an explosive on surfaces mounted at a certain angle to each other. The collision of these surfaces forms a cumulative jet, and the motion of the propelled plate along the fixed one produces a tangential displacement of the surface layers. The resulting tangential discontinuity in velocity is accompanied by the accumulation of perturbations. The cumulative jet destroys oxide /6
films and other nonmetallic inclusions and entrains them from the surfaces to be welded. The perturbations, together with the tangential displacements, cause the simultaneous formation of "waves" in the surfaces to be joined at the points of impact, thereby making it possible for them to approach to within the distances necessary for the creation of metallic bonds, while at the same time increasing the area of the joint.

3. In explosion welding the type of explosive is of major importance. As experiments have shown, the most suitable for this purpose are low-density explosives in granular form (hexogen, etc.).

4. Explosion welding could be used for making blanks for bimetallic rolling, for plating the surface of structural steels with metals or alloys with special physical or chemical properties, and also for welding semi-finished products and certain parts made of inhomogeneous materials. In the latter case, it would be necessary to develop special technical processes. A promising development is the combination of explosion welding with stamping and forging.

The possibility of using the energy of an explosion for welding purposes has also been noted by foreign authors [8,9].

The authors of this article wish to express their gratitude to Academician M. A. Lavrent'yev for his valuable counsel and assistance.

REFERENCES

1. Lavrent'yev, M. A. Kumulyativnyy zaryad i printsipy ego raboty (The Cumulative Charge and How It Works). Upsekhi matematicheskikh nauk. Vol. XII, No. 4, 1957.

2. Baum, F. A., Stanyukovich, K. P. & Shekhter, B.I.: Fizika vzryva (The Physics of Explosion), Moscow, Fizmatizdat, 1959.
3. Landau, L.D. and Lifshits, Ye. M.: Mekhanika sploshnykh sred (The Mechanics of Continuous Media), Gostekhteorizdat, 1954.
4. Andreyev, K. K. and Belyayev, A. F.: Teoriya vzryvchatykh veshchestv (The Theory of Explosives), Oborongiz, 1960.
5. Aynbinder, S. B.: Kholodnaya svarka metallov (The Cold Welding of Metals), AS Latvian SSR, Riga, 1957.
6. Al'tshuler, A. V., Krupnikov, K. K., Ledenev, B. N., et al. ZhETF (Journal of Experimental and Theoretical Physics), Vol. XXXIV, No. 4, 1959.
7. Steel. 1959, Vol. 145, No. 18, pp. 90-91.
8. Iron Age, 1961, No. 4.
9. Metalworking Production, 1961, 24, No. 5.

FARADAY TRANSLATIONS
15 PARK ROW
NEW YORK 38, N. Y.

NASA TT F-140
National Aeronautics and Space Administration.
EXPLOSION WELDING. (Svarka vzryvom,) V. S. Sedykh, A. A. Deribas, Ye. I. Bichenkov, and Yu. A. Trishin. March 1963. i, 12p. OTS price, $0.50. (NASA TECHNICAL TRANSLATION F-140. Translation from Svarochnoye Proizvodstvo, No. 5, 1962, 3-6. (USSR))

The possibility of welding metals of the same and different types, and also of obtaining welded joints of large area, by means of an explosion has been experimentally established. The experiments show that the types of explosives used are of major importance, the most suitable for this purpose being low-density explosives in granular form.

I. Sedykh, V. S.
II. Deribas, A. A.
III. Bichenkov, Ye. I.
IV. Trishin, Yu. A.
V. NASA TT F-140
VI. Svarochnoye Proizvodstvo, No. 5, 1962, 3-6 (USSR)

NASA

NASA TT F-140
National Aeronautics and Space Administration.
EXPLOSION WELDING. (Svarka vzryvom.) V. S. Sedykh, A. A. Deribas, Ye. I. Bichenkov, and Yu. A. Trishin. March 1963. i, 12p. OTS price, $0.50. (NASA TECHNICAL TRANSLATION F-140. Translation from Svarochnoye Proizvodstvo, No. 5, 1962, 3-6. (USSR))

The possibility of welding metals of the same and different types, and also of obtaining welded joints of large area, by means of an explosion has been experimentally established. The experiments show that the types of explosives used are of major importance, the most suitable for this purpose being low-density explosives in granular form.

I. Sedykh, V. S.
II. Deribas, A. A.
III. Bichenkov, Ye. I.
IV. Trishin, Yu. A.
V. NASA TT F-140
VI. Svarochnoye Proizvodstvo, No. 5, 1962, 3-6 (USSR)

NASA

NASA TT F-140
National Aeronautics and Space Administration.
EXPLOSION WELDING. (Svarka vzryvom.) V. S. Sedykh, A. A. Deribas, Ye. I. Bichenkov, and Yu. A. Trishin. March 1963. i, 12p. OTS price, $0.50. (NASA TECHNICAL TRANSLATION F-140. Translation from Svarochnoye Proizvodstvo, No. 5, 1962, 3-6. (USSR))

The possibility of welding metals of the same and different types, and also of obtaining welded joints of large area, by means of an explosion has been experimentally established. The experiments show that the types of explosives used are of major importance, the most suitable for this purpose being low-density explosives in granular form.

I. Sedykh, V. S.
II. Deribas, A. A.
III. Bichenkov, Ye. I.
IV. Trishin, Yu. A.
V. NASA TT F-140
VI. Svarochnoye Proizvodstvo, No. 5, 1962, 3-6 (USSR)

NASA

NASA TT F-140
National Aeronautics and Space Administration.
EXPLOSION WELDING. (Svarka vzryvom.) V. S. Sedykh, A. A. Deribas, Ye. I. Bichenkov, and Yu. A. Trishin. March 1963. i, 12p. OTS price, $0.50. (NASA TECHNICAL TRANSLATION F-140. Translation from Svarochnoye Proizvodstvo, No. 5, 1962, 3-6. (USSR))

The possibility of welding metals of the same and different types, and also of obtaining welded joints of large area, by means of an explosion has been experimentally established. The experiments show that the types of explosives used are of major importance, the most suitable for this purpose being low-density explosives in granular form.

I. Sedykh, V. S.
II. Deribas, A. A.
III. Bichenkov, Ye. I.
IV. Trishin, Yu. A.
V. NASA TT F-140
VI. Svarochnoye Proizvodstvo, No. 5, 1962, 3-6 (USSR)

NASA